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An Analysis of the Effect of Environmental Factors on Paddy Rice Yields

A Case Study from the Northern Region of the Greater Chao Phraya Project

by

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I Introduction

This study analyzes statistically the effect of environmental factors on wet season paddy rice yields in the Northern Chao Phraya Irrigation Project of Thailand.[1] Prior to the construction of the main irrigation systems under the Project beginning in 1952, extensive paddy cultivation had been dominant in the region by means of natural flooding irrigation. Under a Ditches and Dikes Project, construction of water distribution ditch systems has been underway since 1962, being almost completed as of today. Further improvements in the water distribution system are planned. They include work on an irrigation and drainage project at the terminal stage and a crop diversification project. The former aims at land consolidation to enable more intensive paddy cultivation through the input of modern agricultural techniques. The latter aims at introducing a system of double-cropping in rice and other commercial crops thanks to the improved water supply the region will have in the dry season. Among the many agricultural areas in Thailand, this region has been given priority for the consolidation of land for paddy cultivation. And the area is being given close attention as a future commercial rice producing area of the country.

This region produces 10% of the total rice production of Thailand. The yield level of the region is 470 kg/rai (2.94 ton/ha). This is about 70% higher than the Thai national average of 280 kg/rai (1.75 ton/ha).[2] Except for extensive mechanization of

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1) All data in this paper, unless otherwise noted, refers to the subject region, that is, to the 17 projects in the Greater Chao Phraya Project: Pholathep, Thabote, Samchook, Samchook Extension, Phophraya, Boromathat, Chanasutr, Yangmanee, Phakhai, Maharat, Namnoi-Maharat, Manorom, Chongkae, Khoke Krathiam, Roengrang, Thaluang, and Nakhonluang.

2) The yield of 470 kg/rai is based on a crop cutting survey by the RID, while the national average of 280 kg/rai is the statistical value assessed by the Rice Department. Royal Irrigation Dept., 1969, *Report on the Statistical Survey of Areas and Yields of Rice Production in Irrigation Projects, 1968*, Bangkok: RID (in Thai).

ploughing by tractors, modern agricultural techniques have not enjoyed any widespread application, like the use of new high-yielding dwarf rice variety or the use of chemical fertilizer and pesticide. Although the irrigation system has been consolidated and improved to some extent, paddy cultivation in the region still remains in the conventional stage of cultivation. Therefore, the author considers it still possible to explain the level of paddy yields in the region largely in terms of natural environmental factors such as water, soil and climate. In this paper, the author aims at a comprehensive quantitative evaluation of the natural environment of present paddy cultivation by analyzing factors relating to paddy yields.

The importance of water control, as mentioned above, should be fairly obvious. Many discussions of the topic have been concerned with this region too. The author feels unsatisfied with these discussions, even when they reach what he feels to be correct conclusions, because they usually lack verifiable data. Some papers discuss the effects of environmental factors on rice yields using some statistical data. They are those of Ruttan, V. W. *et al.*, S. Ishikawa, and T. Tanaka.

Ruttan *et al.*[3] analyzed the technical and environmental factors involved in the growth of rice production in yield differentials among provinces, using the 1947/48-63/64 provincial data. Their conclusion is that: 'After the effects of the environmental factors are taken into account, there is little yield increase or yield differential left to be explained by such factors as new varieties, better cultural practices or more intensive use of technical inputs...or economic or social differentials among provinces. The environmental factors under which rice is grown are primarily soil, season, water and weather differentials.'

Ishikawa[4] analyzed the effect of irrigation and fertilization on the yield of rice in Southeast Asian countries and the States of Madras and West Bengal in India. He used the method of the simple correlation analysis. He concluded that 'An antecedent input is the investment for irrigation in the Central Plain of Thailand',[5] in which he assumed that irrigation is expressed by the ratio of irrigated area to total paddy field area.

Tanaka[6] analyzed the heterogeneous function of production,

$$Y=f(\alpha A,\ L,\ K,\ T,\ U),$$

using the provincial census of agriculture of 1960. He stated as his conclusion that

3) Ruttan, V. W., A. Soothipan and E. C. Venegas, 1966, "Technical and Environmental Factors in the Growth of Rice Production in the Philippines and Thailand," *Rur. Econ. Problems*, Vol. III, No. 1.

4) Ishikawa, S., 1966, "Analysis of Antecedent Investment in Agricultural Development, Part 1," *Asian Studies*, Vol. 12, No. 4. (in Japanese).

5) Antecedent investment refers to the kind of investment that maximizes land productivity under a specific level.

6) Tanaka, T., 1967, "The Structure of Asian Agriculture and Its Heterogeneous Production Function. Case studies in Thailand, the Philippines, and Malaya," *Asian Economy*, Vol. 8, No. 11. (in Japanese).

'The contribution of A (land-augmenting effect of irrigation) is significant, but all other factors such as T (technical input) are not significant in the case of Thailand.'

After analyzing regional differences in rice production, H. Fukui[7] divided the Bangkok Plain into 13 subregions based on rice yield and rice cultivation environmental conditions, including water conditions, soil suitability, fertilization, and other technical inputs.

The former three cases were based on macro-scopic statistical data at the provincial level. Therefore, the discussions are necessarily thusly limited too.

The author gathered some detailed primary information on such technical and environmental factors as methods of rice cultivation, irrigation and drainage, and meteorological factors while conducting a field survey of irrigation and drainage in the region in 1969. An statistical analysis of the environmental factors of rice cultivation using these datailed data will hopefully contribute to filling earlier gaps in approach to the subject and help in providing an appreciation of environmental factors on yield. Therefore, the author will try to offer an interpretation of the results of the analysis, knowing that the statistical method is inadequate alone to clarify the complicated question of rice 'yield'. Substantial data on environmental factors will be presented. Factors other than the natural environment, such as rice varieties, fertilization, application of pesticides, the application of other technical inputs, the labor force invested, and the socio-economic conditions under which rice cultivation is carried out are not the focus of this study. This is because primary data relating to these factors are not available.

II Methods and Procedures of the Analysis

Environmental factors considered to have bearing on the yield of "unhusked rice" were selected and numerized. Then an analysis of variance was carried out to find significantly effective factors and to investigate the significant difference of sample yield means between each level of the factor. After extracting certain significantly effective factors, multiple linear regression analysis was carried out by taking these factors as linear elements to derive an equation of regression describing the relation between yield and environmental factors.

Transplanted and broadcast rice are treated separately in this analysis, because such factors as rice variety, growing period, and water management are quite different between the two and the amount of irrigated water, effective precipitation and cumulative temperature are accordingly different also.

The yield in each sampling plot is treated by an analysis of variance, whereas the average yield in a zone is handled by multiple linear regression analysis. The FACOM

7) Fukui, H., 1969, "Rice Culture in the Central Plain of Thailand, Subdivision of the Central Plain and the Yield Components Survey in 1966," *Southeast Asian Studies*, Vol. 6, No. 4.

230-60 computer of Kyoto University was employed to carry out all calculations in this paper.

1. Analysis of variance

Analysis of variance was carried out for one and two variable case. Although the method and procedure of the analysis of variance employed in this paper is the usual one,[8] some innovations were introduced: in the method of selecting factors for calculation, in the dividing of levels, and in the making of a special calculation table in the computer to treat of various complicated data.

Environmental factors taken into account include total growing period (DATA 1), vegetative growing period (DATA 2), crop height (DATA 3), amount of irrigated water (DATA 4), precipitation (DATA 5), total water supply (DATA 6), maximum depth of water in the field (DATA 7), depth of water in the field at the heading stage (DATA 8), cumulative temperature during the growing period (DATA 9), soil series number (DATA 10), quantity of surplus or deficit irrigated water (DATA 11), and efficiency of irrigation (DATA 12).

2. Analysis of multiple linear regression

A source program of 'method of least square analysis for large capacity and multiple elements (SLSM 14)' has been developed by the Economic Planning Agency of Japan.[9] The author employed this program after rewrote parts of it to meet the requirements of Kyoto University's computer. Soil factors were treated as dummy variables[10] because they are difficult to numerize.

III Data

1. Sources of data analyzed

(1) Paddy rice yields

The Royal Irrigation Department has been conducting surveys of paddy rice yields within the irrigated region. The number of sampling sites averages about 5,000 in any given year and about 250 surveyors are normally employed.[11] The number of sample sites within the 16 irrigation projects in the analyzed region is 327, of which 217 are in transplanted rice fields and 110 in broadcast rice fields. The sampling sites in the

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8) Kishine, T., 1967, *Statistics.* Tokyo: Yokendo, pp. 417-482. (in Japanese).

9) Institute of Economics, Economic Planning Agency of Japan, 1968, "Computer Techniques for Economic Analysis," Tokyo: Economic Planning Agency, pp. 1-36. (in Japanese).

10) Johnston, J., 1963, *Econometric Methods*, New York: McGraw-Hill, pp. 221-228.

11) RID, 1967, *Report on the Statistical Survey of Areas and Yields of Rice Rroduction in Irrigation Projects, 1958-66*, Bangkok: RID. Besides the RID, the Rice Department and National Statistical Office conduct their own yield surveys of rice production. Only data given by the RID, however, is used in this analysis.

region are indicated in Fig. 1.

Sampling procedures:

a. Division of each survey zone (10,000-50,000 rai) into 12 approximately equal blocks; then selection of 4 blocks at random.

b. Division of each of these 4 blocks into 12 approximately equal plots; then selection of 4 plots at random.

c. Measurement of the center of each plot to get a precise crop cutting area of 100 square meters (10×10 m).

d. Crop cutting, threshing, cleaning, weighing of new (fresh) seeds, and reweighing of seeds after drying for 3-7 days.

(2) Crop outlook reports

Each project office of the RID has a staff to observe agricultural data such as ploughing, land preparation for transplanting, transplanting, harvesting, the growth stage of the plants, crop height, and depth of water in the field. Such observation is usually carried out at each zone of the project throughout the growing period of the rice. Information thus obtained is brought to the Water Operation Board and Center of the RID in Bangkok as a weekly crop outlook report.[12]

(3) Meteorological data[13]

Meteorological elements that affect the growth and thus the yield of paddy rice are precipitation, average daily temperature, cumulative temperature over the entire growing period, daily fluctuation of temperature, length of day hours and net radiation. Only records on daily precipitation and daily average temperature are available, however. Rain gauge networks of the Meteorological Department and the RID are distributed rather densely over the area. Daily average temperatures are recorded at the Bangkok, Bangkok airport(Dong Muang), Kanchanaburi, Lopburi, Nakhonsawan, Prachinburi, and Suphanburi meteorological stations.

(4) Data relating to irrigation

Necessary information on water conditions includes the following:
a) quantity of irrigated water, b) inflow and outflow volume of water to and from adjacent areas, c) depth of water in the field, and d) an efficiency index taking into account consolidation of water distribution systems, water surpluses and deficits, relative difficulty of water supply, and ultimate efficiency of irrigation.

Although records of the amount of water irrigating each project are not available, their values can be calculated from the data on daily discharge at each regulator given in Fig. 1. Records of up and down-stream water levels and the discharge at each regu-

12) Kaida, Y., 1969, "A Field Report of an Irrigation Research in the Chao Phraya Basin (News from the Field)," *Southeast Asian Studies*, Vol. 7, No. 3. (in Japanese).

13) Data is based on unpublished data records of the Hydrology Section, RID., 1968 and "Weekly Weather Report," Meteorological Dept., 1968-9, Nos. 15-52/1968 and 1-14/1969.

lator are available at each project office and at the WOBC.[14]

(5) Soils

Soil maps scale 1/50,000 published by the Soil Survey Division of the Land De-

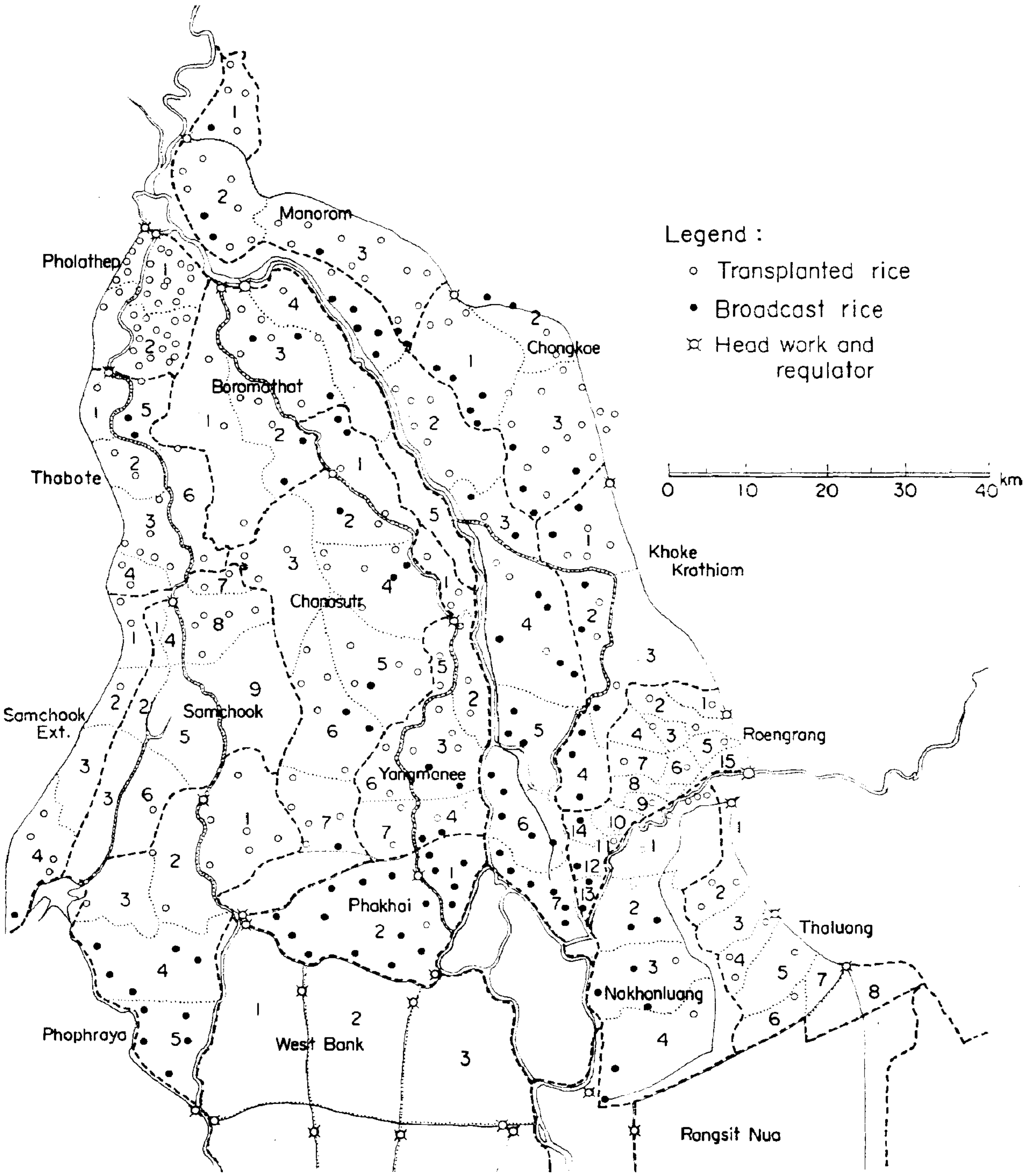

Fig. 1 Sampling sites of 1968 crop cutting rice yield survey in the subject region; and irrigation project and zone boundaries

14) Water Operation Board and Center, RID., 1968-9, "Daily Records of River and Canal Discharge, Water Gauge Reading of the Greater Chao Phraya Project (unpublished; in Thai).

velopment Department cover almost all areas of the subject region.[15] These maps include areal division of soil series and land suitability for irrigated rice. The soil series and land suitability of each yield survey plot can be identified from these sheets of maps. Some knowledge of local micro-topography can also be gained from these soil maps. The Samchook, Samchook Ext., Phophraya, Phakhai, and Nakhonluang projects are without soil maps.

2. Methods of readjustment of data

All the environmental factors at the yield survey plot should ideally have been observed or measured at the same site. Unfortunately they were not, because the particular purpose in mind in each instance was different.[16] Therefore the measured value of the various factors must be readjusted so that each factor represents as well as possible the average value in each small area. The smallest unit of the observation and measurement in the crop outlook report was the zone. Therefore, the other factors required for the analysis were all readjusted in terms of average values at the zone level.

(1) Division of the zone in each project area (Fig. 1)

Each project area of the subject region is divided into 2 to 7 zones for the purpose of optimizing water management. The division boundary is principally determined by the irrigation canal system. Usually a lateral canal commands a zone. The average acreage of a zone is 53,000 rai (46,000 rai in the subject region), ranging from 5,000 to 140,000 rai.

(2) Crop outlooks

The graphs shown in Appendix 2 (lowermost and second from the bottom) were made from the table of the crop outlook report. Then the following information was obtained by reading the graphs:

Growth period: The period between the time when rice broadcasting or transplanting covered half of the area of each zone and the time when harvesting was completed over half the area.

Vegetative growth period: The period between the time when broadcast or transplanted plants covered half of the area of each zone and 4 weeks before half of the area had reached the heading stage.

Crop height: The maximum crop height at harvest time.

Water depth in the field: In some zones, the records of water depth are written in terms of average depths in low-lying, middle, and high land; but in other zones, only the average value in the zone is recorded as a general value. Thus the author considered

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15) van der Kevie, *et al*, 1965-68, *Soil Survey Reports of the Land Development Department, Chao Phraya Irrigation Project* (9 volumes).

16) Details are not given because the author has not seen the relevant so-called 'investigation cards' at first-hand.

the average depth of water in a transplanted area to be the mean value of middle and high land, and the depth in a broadcast area to be the mean value of middle and low-lying land. In zones where only one value as a general value is recorded, data was adjusted (sometimes rather subjectively, in accordance with the author's own field observations conducted in the rainy season in 1969). Maximum depth and average depth at the heading stage (averaged from between 4 weeks before and 1 week after heading) were taken as indexes of water depth.

(3) Amount of irrigated water and the efficiency of irrigation

Amount of irrigated water: Weekly discharge at each regulator (Q_i) was calculated from daily records at the regulator. Then, the discrepancy between discharge at up and down-stream regulators ($Q_{i-1}-Q_i$) was noted. Then, the average weekly quantity of irrigated water to a unit area (expressed in terms of depth) was calculated by dividing the ($Q_{i-1}-Q_i$) by the acreage of the area. That is $D_i=(Q_{i-1}-Q_i)/A_i$. The unit area here is usually a project.

At the projects upstream, such as Pholathep, Boromathat, Maharat and Manorom, the amount of irrigated water is usually more precisely calculated, because irrigation water is diverted from above the Chao Phraya Dam into small canals which cover a relatively small area.

The index of amount of irrigated water is taken to be the accumulated depth of water supplied to the subject zone over the entire crop growing period. Accumulated curves of these values in each zone are shown in the second column from the top in the graphs of Appendix 2.

Surplus or deficit water and efficiency of irrigation: They are defined as follows:

Surplus or deficit water

=gross irrigation water−net water requirements ···(1)

Efficiency of irrigation

=(net water requirements/gross irrigation water)×100% ···(2)

Net water requirement

=(number of growing days till flowering)×(average daily evapotranspiration +average daily percolation of water)+(water requirement for land preparation)−(total effective precipitation during the period) ···(3)

Estimations for the design value of evapotranspiration and the ratio of effective precipitation for the Greater Chao Phraya Project are presented by the RID.[17] Each factor in equation (3) was determined by averaging each factor between the months of May and November.

	Transplanted rice	Broadcast rice
Evapotranspiration	6.0 mm/day	5.8 mm/day

17) Hydrology Section, RID., 1962, *Hydrology of the Mae Klong River Basin and Water Studies of the Mae Klong Irrigation Project, Thailand*, Bangkok: RID.

Water requirement for land preparation	16.0 mm	—
Water requirement for sowing	—	30.0 mm
Percolation loss	1.0 mm/day	1.0 mm/day
Ratio of effective precipitation	75 %	75 %

(4) Climatological factors

Precipitation: Weekly precipitation was calculated at each rain gauge station from the daily records, then the weekly point precipitation data was transformed into figures for the weekly area precipitation in each zone by applying the Thiessen method. Total precipitation between the time of the beginning of transplanting or of sowing and the time when harvesting was carried out over half the area was taken as the total available precipitation during the entire growing period. Here rainfall loss by interception or evaporation was not considered. Cumulative curves of available precipitation are shown in the top column in the graphs of Appendix 2.

Temperature: Meteorological stations which have redords of daily temperature are so sparsely distributed in the region that accumulated temperature required for the analysis have to be assigned for zones near these stations.

(5) Soils

Soil characteristics of each sampling plot, as identified on the soil map of scale 1/50,000, were classified in terms of a) land suitability, b) great soil group, c) land form, and d) land form and parent material.[18] The criteria for the classification are indicated in Appendix 1.

3. Rearrangement of data analyzed

Table 1 Average value and standard deviation of each factor

	Transplanted Rice		Broadcast Rice	
	average	std. dev.	average	std. dev.
Whole growing period (week)	22	2	29	2
Vegetative growing period (week)	13	2	21	2
Crop height (cm)	120	27	145	31
Precipitation (mm)	510	90	680	90
Irrigation water supply (mm)	950	200	1150	270
Total water supply (mm)	1500	220	1600	220
Surplus or deficit irrigated water (mm)	280	230	330	240
Efficiency of irrigation (%)	73	21	69	23
Max. water depth (cm)	27	12	74	26
Water depth at the heading stage (cm)	17	13	53	26
Cumulative temperature (week-degrees)	640	67	860	64
Paddy yield per rai (kg)	490	73	420	81

18) Cf. soil survey reports mentioned before and also Kawaguchi, K. and K. Kyuma, 1969, *Lowland Rice Soils in Thailand*, Kyoto: The Center for Southeast Asian Studies of Kyoto University.

The result of the rearrangement of each factor in each zone, readjusted from data at each sampling plot is tabulated in Appendix 3. The average value and standard deviation of each factor in each zone are given in Table 1.

4. Discussion of data

The data, because of special difficulties, must be carefully examined before discussing the results of the analysis. Problems concern a) the generality of the climatic conditions in 1968, b) the accuracy of the data and the methods employed for the measurement of each factor, and c) errors involved in transforming the data from the point stage to the areal stage.

(1) Characteristics of the climate in 1968

The 1968 water year was an extremely dry one. Annual precipitation in 1968 was less than the annual average by 200 mm. Discharge of the Chao Phraya River system was extremely low, indicating a probable return period of 100 years.[19] All-time low records for the discharge of this river and the water storage capacity of the Bhumiphol Dam were revised using 1968 values.

Damaged paddy field acreage in the subject region, that is, land suffering mostly from localized drought, amounted to about 60,000 rai, or about 1.5 % of the total area.

(2) Problems in the accuracy of data and methods of measurement

Yield surveys: In the third stage, the selection of sample cutting plots of 10×10 m, the person performing the task is often likely to choose from areas that offer easy access; as this usually results in the selection of better plots, it is not random in the strict sense of the word. Crop cutting surveys are said usually to give higher yields compared with other methods of estimation.[20]

Crop outlooks: It is not easy to determine precisely from crop outlook reports such things as the length of the total growing period and the date of heading, because sowing, transplanting, and harvesting usually continue over a one-month period in each zone. In this analysis, since factors such as amount of irrigated water, precipitation, efficiency of irrigation, depth of water in the field, etc. are all calculated on the basis of growth stage (or growth period), uncertainty about the exact length of the period greatly affects the reliability of other factors.

Methods for estimating the average depth of water in the field are quite uncertain, especially over larger zones. Such estimations overlook variations in water depth due to local topographic conditions. However, the author considers the water depth records

19) Based on personal communication with the WOBC of the RID.

20) The statistical data of the RID, the Rice Department, and the National Statistical Office do not at all coincide. Yields given by the RID are the largest. As mentioned before, RID conducts the crop cutting surveys; the latter two agencies make estimations of the yield per rai by estimating total production in each Amphoe. The harvested area in each Amphoe, although estimated, is not actually surveyed by the latter two departments; this can sometimes prove disastrous.

given in the crop outlook reports to be rather reliable because physiographic conditions and water regimes in this region are fairly homogenous especially compared with Japan. Also, inasmuch as no other water depth records for the region are available, there is no alternative but to utilize the given data.

In areas where the amount of water inflow or outflow to and from adjacent areas through river drainage channels, depressions, and the like is unmeasurable, or in areas where there is an indeterminable runoff from marginal mountaneous areas, it is of no use trying to estimate the amount of irrigated water precisely. Therefore, in the projects of Phophraya and Phakhai, in the lower reaches of Yangmanee, and in some parts of Nakhonluang, where such unmeasurable inflow is evident, irrigated water depths have not been calculated.

(3) Problems involved in transforming data to an areal scale

In this analysis, yields measured at single geographical points are compared with environmental factors measured or estimated for large-scale areas. Environmental factors are treated in the following area-size units:

Depth of water in the field: Minimum, ca. 2,000 rai; maximum, ca. 8,000 rai.

Irrigated water depth: Where water is supplied through canals which are directly diverted from the Chao Phraya River, minimum, 5,000 rai; maximum, 210,000 rai. Where water is supplied through main canals, minimum, 58,000 rai (Thabote); maximum, 460,000 rai (Chanasutr).

Precipitation: Minimum, 10,000 rai; maximum, 200,000 rai.

Errors in transformation due to disaccord in the areal unit could not be reduced. One way of minimizing this error, however, is to treat yield data as an average in a zone. Yield data used in multiple regression analysis is treated in this way. However, problems arise when yield data is treated as an average. For one, it becomes difficult to pick out "within groups" variance; and for another, it becomes difficult to carry out the analysis of variance for two variable case because the sample size is too small.

IV Results and Discussions

1. Analysis of variance for one variable case

Differences in yield levels among tracts and projects were calculated, then the effect of primary and secondary environmental factors on yield levels was estimated. In Table 2, the number of levels, sample sizes (with their degrees of freedom), and F-values are tabulated for each factor.

Factors that have significant effect on the yield level of transplanted rice include crop height, precipitation, amount of irrigated water, total water supply (irrigation+precipitation), surplus or deficit in the water supplied, depth of water at the heading stage, and land suitability. In the case of broadcast rice, total growing period, crop

Table 2 F-values for each factor in the results of analysis of variance for one variable case

Factor		Transplanted Rice			Broadcast Rice		
		No. of levels	Degrees of freedom	F-value	No. of levels	Degrees of freedom	F-value
Region	Tract	5 217	4 212	4.01**	5 110	4 105	0.24
	Project	15 217	14 201	3.06**	13 110	12 94	3.53**
Crop	Growth period	4 215	3 209	0.27	5 110	4 105	14.62**
	Height	6 159	5 153	4.54**	6 77	5 71	2.34(*)
Soil	Land suitability	4 192	3 188	3.45*	4 82	3 78	6.06**
	Great soil group	4 192	3 188	1.78	4 82	3 78	0.53
	Parent material +land form	8 192	7 184	1.51	7 82	6 75	1.75
	Land form	6 192	5 186	1.79	5 82	4 77	2.47(*)
Water	Irrigation	8 199	7 191	3.25**	4 78	3 73	0.86
	Rainfall	5 216	4 208	4.45**	4 110	3 106	2.27
	Total water supply	5 187	4 182	6.67**	6 81	5 75	1.34
	Ponded water depth (max.)	5 170	4 165	1.10	6 101	4 95	2.13
	Ponded water depth at the heading stage	6 169	5 163	3.85**	5 87	4 81	4.26**
	Surplus of deficit irrigated water	10 189	9 179	2.78**	10 74	9 64	2.58*
	Efficiency of irrigation	10 192	9 182	1.04	10 70	9 60	1.48
Climate	Temperature	4 214	3 209	0.87	5 110	4 104	10.68**

* significant under 95 % level, ** 99 % level

height, efficiency of irrigation, depth of water at the heading stage, land suitability, and land form are the significant factors. Differences between individual projects were pronounced in the case of both. Factors having significant effect on yield level are illustrated in Fig. 2 (1)-(12) in terms of their relationship to that yield.

2. Analysis of variance for two variable case

Results of the analysis of variance for two variable case are compiled and tabulated in Table 3. In the case of transplanted rice, significant effect of interaction was found to exist between surplus or deficit irrigated water and land suitability. In the case of broadcast rice, relationships appeared between the following: amount of irrigated water

Table 3 Interaction effects of two factors

	1	2	3	4	5	6
1 Irrigation water supply		/	/	*	/	/
2 Water depth at the heading stage	—		?	*	*	**
3 Efficiency of irrigation	?	?		?	/	/
4 Land suitability	—	—	?		/	/
5 Land form	/	/	?	/		/
6 Growing period	/	—	?	/	/	

Upper right: Broadcast Rice; lower left: Transplanted Rice

Note: *, ** significant, ? unknown, — insignificant, / not calculated

and land suitability; surplus or deficit irrigated water and land suitability; and depth of water at the heading stage and land form. Where transplanted and broadcast rice are not separately analyzed, significant interaction appeared between land suitability and depth of water at the heading stage; land suitability and surplus or deficit irrigated water, and land suitability and efficiency of irrigation.

3. Discussion of the effect of specific factors

(1) Variations of yield level among tracts[21] and projects

When the region is divided into 5 tracts, as shown in Fig. 2 (1), the yield level of transplanted rice in the water conservation area is significantly lower than that in all other tracts. Yet, no significant variation is found among tracts outside the water conservation area. Among all 5 tracts, including the water conservation area, no significant variation in the yield level of broadcast rice is noted. The reasons for this are probably as follows. Where transplanted rice is dominant, soil and water regime conditions apparently differ between water conservation areas and gravitational irrigation areas. Yet where broadcast rice is dominant, differences in environmental conditions between these two areas are very small, since late-maturing rice varieties are grown under deep water conditions everywhere.[22]

If the region is divided into 16 projects, as shown in Fig. 2 (2), significant differences in yield levels of transplanted rice are found among the various projects. Generally, projects furthest upstream have highest yields. And the yield level lowers the further downstream a project is. Thus the Pholathep, Boromathat, and Manorom projects comprise the area of highest yield. They draw irrigation water directly from the Chao Phraya River through several of their own smaller canals and not through the main

21) The subject region is divided into 5 tracts based on river system boundaries. They include the Suphan river tract, the Noi River tract, the Maharat tract, the Chainat-Pasak canal tract, and a water conservation area where gravitational irrigation cannot be carried out due to physiographic restrictions.

22) Fujioka, Y, and Y. Kaida, 1967, "Irrigation and Drainage in the Bangkok Plain of Thailand," *Southeast Asian Studies*, Vol. 5, No. 3. (in Japanese).

canal system. Significantly enough, in such downstream projects as Roengrang and Thaluang, yield level differentials are large. Broadcast rice does not show the significant yield differential that transplanted rice does; only the yield is slightly higher in the upper reaches of the Noi River and the uppermost area of the Maharat projects. The yield of floating rice in the Phakhai project reaches no less than 610 kg/rai, being the maximum yield over the entire region.

(2) The effect of water conditions

The following factors significantly affect transplanted rice yields.

i) Precipitation

As Fig. 2 (4) shows, significant differences in yield appear between precipitation levels of 500-600 mm and 600-700 mm; and between levels of 500-600 mm and 700-800 mm. Calculation here shows that precipitation greater than 550 mm is required for good yields. And within the 550-750 mm range, each 100 mm of precipitation has the positive effect of a +30 kg/rai increase in yield.

ii) Amount of irrigated water

As Fig. 2 (3) shows, a difference of no less than 50-60 kg/rai appears at the critical 700 mm level of irrigated water. But beyond 750 mm, yield seems to stay at the same level of 500 kg/rai.

iii) Total amount of water supplied (precipitation+irrigation)

More remarkable is the effect of total supplied water. As shown in Fig. 2 (5), when total water supply is between 800 and 1,800 mm, the less the water supplied, the greater the yield. Significant differences in yield appear at every level of total water quantity.

iv) Depth of water

Yield differentials of 50-60 kg/rai exist between water depth levels of 0-10 cm and 10-20 cm, 0-10 cm and 20-30 cm, and 0-10 cm and 30-40 cm. As the graph in Fig. 2 (6) shows, the shallower the depth, the greater the yield.

In the case of broadcast rice, precipitation, amount of irrigated water, total water supply, and depth of water have negligible effects on yield. The only instance of perceptible difference in yield is evident above and below the 90 cm water depth level at the heading stage. Maximum yield is at the depth of 90 cm. However, it is difficult to extrapolate from this result to explain the effect of water depth on broadcast rice yields in general because the extremely high-yielding floating rice of the Phakhai project was included in the initial calculation in this case.

The foregoing merely describes primary results gained from calculation. Additional concrete results become evident when secondary environmental factors such as surplus or deficit irrigated water and efficiency of irrigation are examined. These are illustrated, as they bear on transplanted rice, in Fig. 3 (1). There one finds the surplus or deficit of water to be 280±230 mm and the efficiency range to be 73±21 % (refer to Table 1).

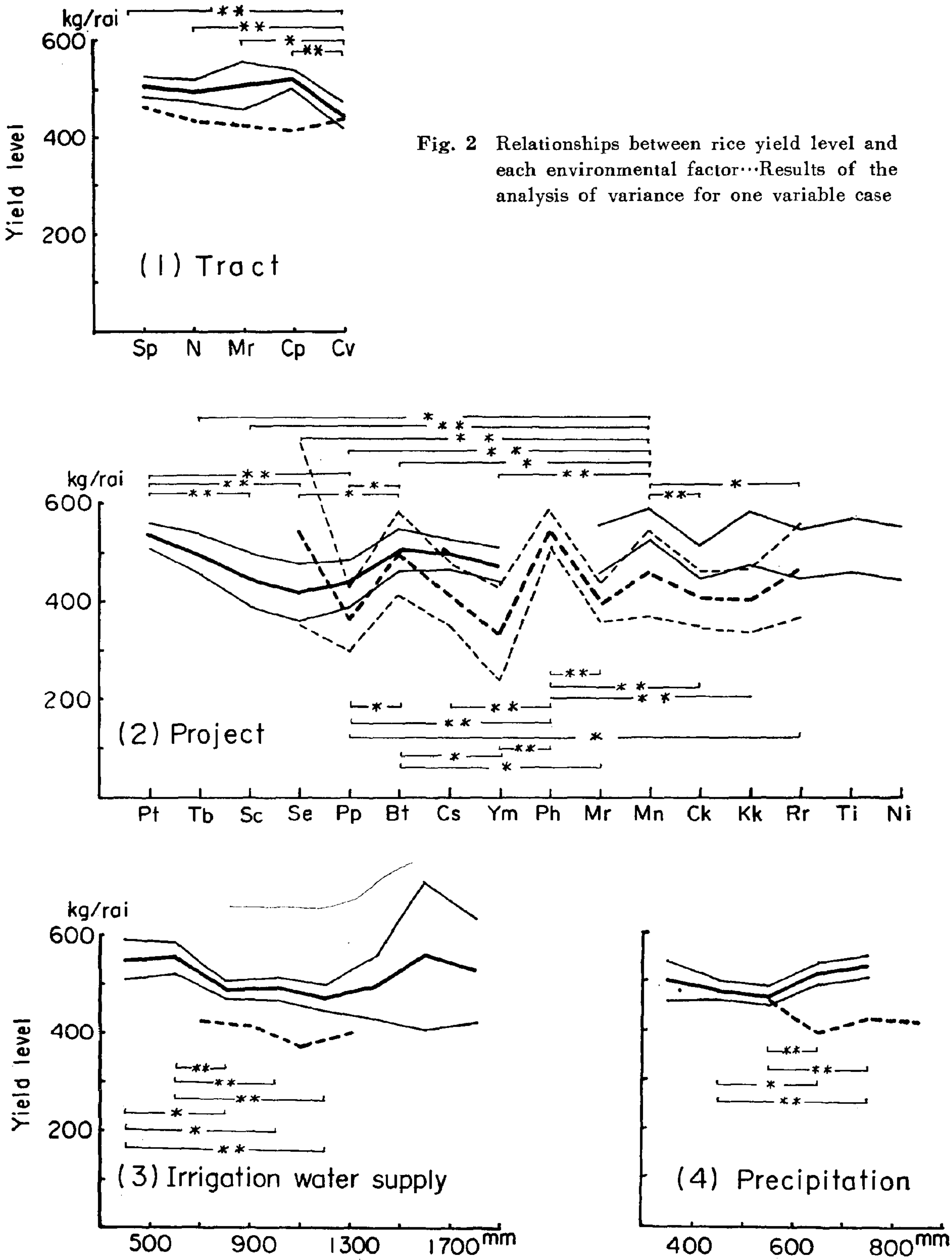


Fig. 2 Relationships between rice yield level and each environmental factor…Results of the analysis of variance for one variable case

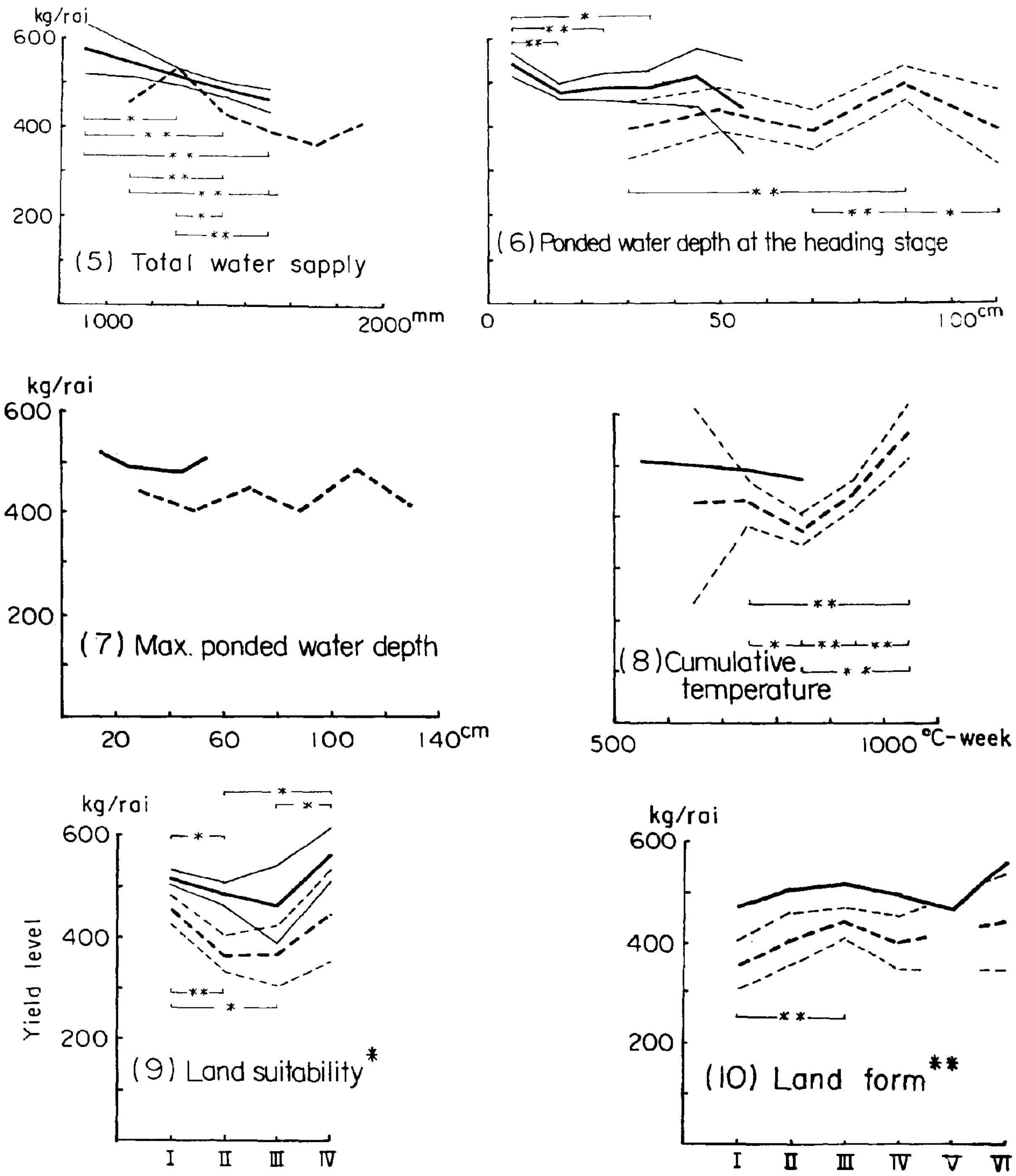


Fig. 2 (continued)

As indicated in Fig. 3 (1), a yield greater than the 500 kg/rai level cannot be attained with more water once surplus water reaches 300 mm (the corresponding efficiency being about 70 %). Yield level goes down as the efficiency of irrigation decreases, though the relationship between these two factors is not particularly significant.

In the case of broadcast rice, as shown in Fig. 3 (2), surplus or deficit irrigated

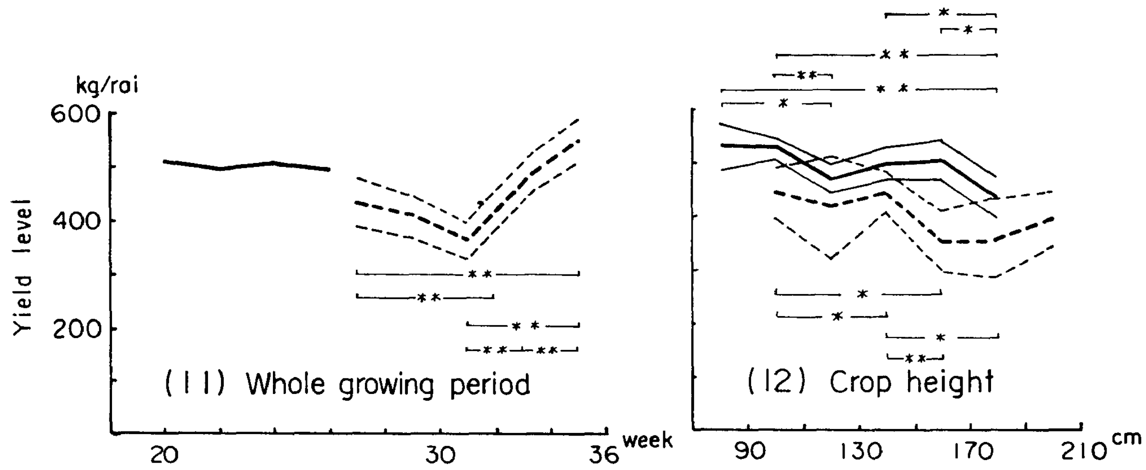


Fig. 2 (continued)

water and efficiency of irrigation do have significant effect on the yield level. In this case, again, yield level is restricted when surplus water comes to about 300 mm, the corresponding efficiency of irrigation being 70 %.

In Figs. 4 (1) and (2), the effect of surplus or deficit irrigated water on transplanted and broadcast rice yields (treated together) is indicated. A significant yield differential appears above and below the 70-80 % irrigation efficiency level.

In some areas in the region, efficiency is very low because the loss of water through diversion, conveyance, and distribution is large. In particular, distribution efficiency in areas covered by small ditches is extremely low due to the incompleteness of the distribution system. For example, where a) paddy field surface is uneven, b) irrigation ditches at the terminal stage are sparcely distributed, and c) where such ditches function inefficiently, concave depressions receive too much water while depth at convex areas remains insufficient, thus reducing efficiency as a whole. The concept that shallower water and smaller supply of irrigation water give preferable water conditions for good rice yields should be accepted with the following proviso: shallower water tables using smaller amounts of irrigated water can be retained only when efficiency of irrigation as a whole is high owing to good topographical conditions and/or good water distribution systems. Such shallow water is not necessarily to be interpreted as a water deficit index.

Both water surplus or deficit and efficiency of irrigation are sometimes used as indexes to indicate topographical conditions and the state of consolidation of water distribution systems. So it comes as no surprise that, as is often stated, rice yields in areas of good water conditions are high as well as stable.

(3) The effect of soil conditions on yield level

Soil in the subject region was classified into four groups based on the criteria shown in Table 1. The most appropriate criterion for this grouping was 'land suitability'; the

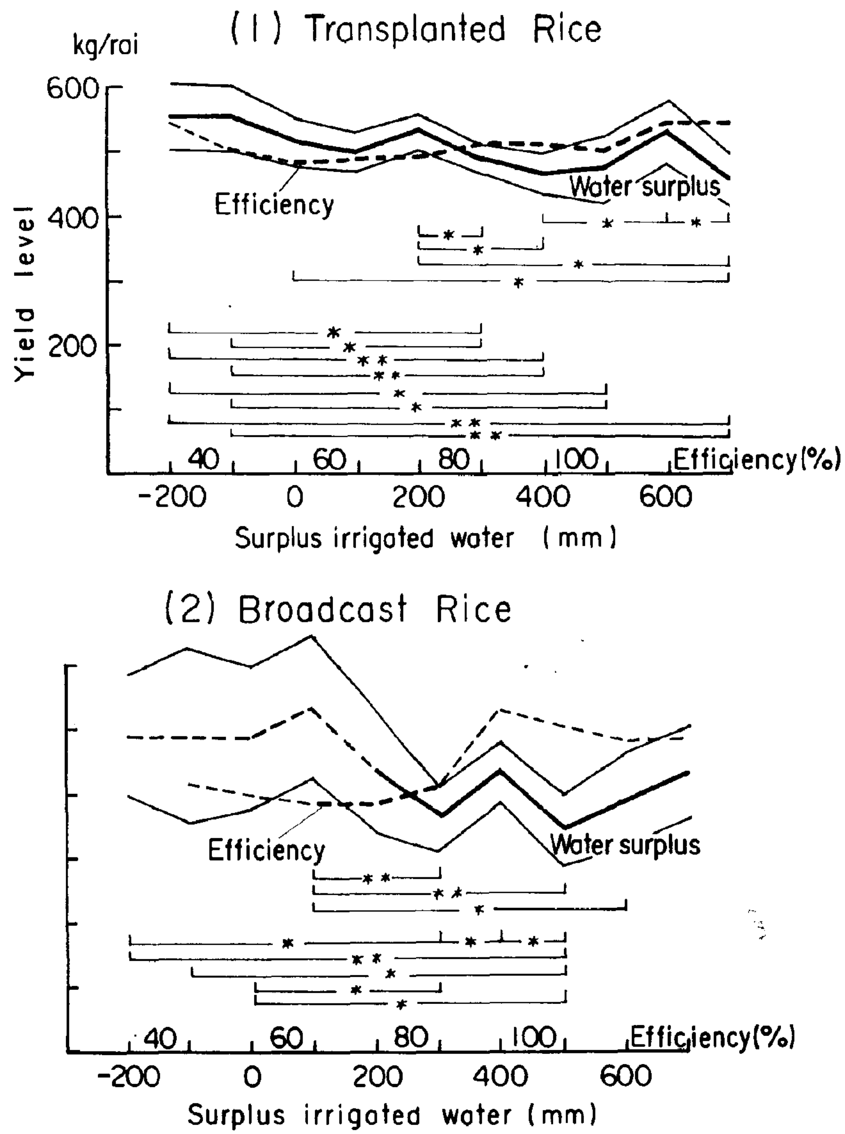


Fig. 3 Relationships between rice yield level and a) Surplus irrigated water, and b) Efficiency of Irrigation

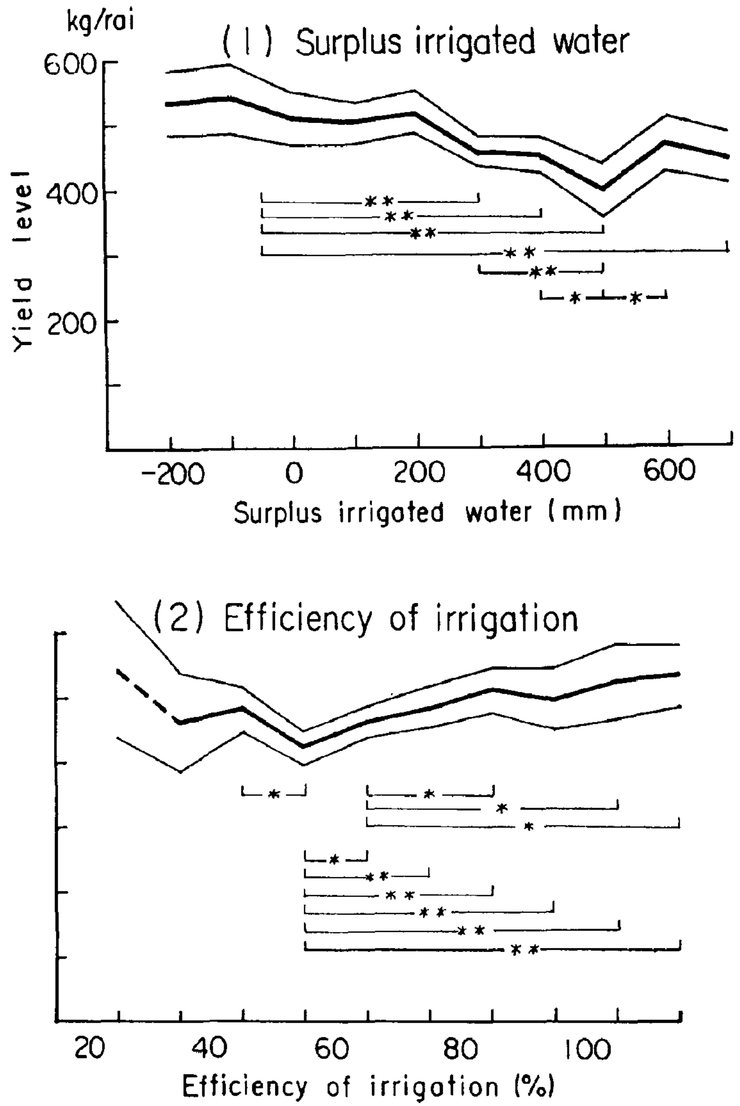


Fig. 4 Relationships between rice yield level and a) Surplus irrigated water, and b) Efficiency of irrigation. (Transplanted and broadcast rice were treated together)

second most appropriate criterion was 'land form'; other criteria proved comparatively meaningless.

Rice grown in areas of land suitability I & IV had significantly higher yields than that in areas II & III. The grouping of land suitability into classes I+IV and II+III is adequate as far as rice yield is concerned, regardless of whether the rice be transplanted or broadcast. The yield differential between the two classes is about 50 kg/rai in the case of transplanted, and about 60 kg/rai in the case of broadcast rice (see Fig. 2 (9)). When soils are classified according to criterion of land form, a significant difference in yield becomes evident only between basin soil and brackich alluvium soil (Fig. 2 (10)); there is no such difference among other soil classes. It happens that maximum yield in this study was attained in basin soil. But land form cannot be a good index for this analysis, because no significant difference in yield appeared among basin, levee, and terrace alluvium soils.

(4) The effects of growing period and crop height

i) Growing period (Fig. 2 (11))

Total growing period of transplanted rice ranged between 20 and 26 weeks averaging 21.9 weeks. The length of period bore no relationship to yield. In the case of broadcast rice, it ranged between 27 and 35 weeks, averaging 29.4 weeks. The longer the growing period (when the period exceeded 31 weeks), the higher the yield was. However, because the long term rice variety taking 33–35 weeks consisted mainly of the high-yielding floating rice of the Phakhai project, this statement may not be true in general for broadcast rice. It is more reasonable to conclude that there is no relation between the total growing period of transplanted and broadcast rice and yield.

ii) Crop height

From Fig. 2 (12) two facts stand out. Transplanted rice lower than 120 cm in height produces slightly higher yields than do taller varieties. And with broadcast rice, plants less than 150 cm in height produce yields greater than taller varieties to the extent of 50 kg/rai. However, relationship between yield and crop height has not yet been scientifically clarified. Furthermore, methods used for observing crop heights recorded in the crop cutlook report are indefinite. Thus it may also be safer not to induce here any relationship between crop height and yield.

(5) Cumulative temperature and other factors

As shown in Fig. 2 (8), cumulative temperature appears to have a significant positive effect on the yield of broadcast rice. However, this is as much a reflection of the total growing period, as seen in Fig. 2 (11). One cannot distinguish between the two.

(6) Effect of interaction of soil and primary water conditions

In the analysis of variance for two variable case, soil (land suitability) is classified into only two classes, I+IV and II+III (cf. Section 3).

Broadcast rice yield is affected by interaction of land suitability and water depth at the heading stage. With transplanted rice, no such effect appears, even though both land suitability and depth of water at the heading stage are in themselves quite significant. This fact would seem to indicate that each factor affects yield independently. However, this is puzzling when we consider that water conditions are essential in classifying land suitability itself.

Other factors that have some interactional effects on broadcast rice yield are total growing period and maximum depth of water; and total growing period and water depth at the heading stage. These trends, are largely influenced by the singularity of yield from the floating rice in the Phakhai project. Consequently the effects of interaction of these factors are not necessarily a generalized feature for broadcast rice.

In this case, two difficulties are involved in the analysis of variance for two variable case. One is concerned with the difficulty of dividing a factor into levels where such division does not lose physical meaning. But with divisions maintaining physical meaning, the calculation table of TAB (J, K, L) in the computer often becomes incomplete with some missing elements, rendering the calculation impossible. Therefore, division of levels is often determined without considering physical meanings in order to make calculation possible. Unfortunately, this reduces the reliability of the results. The second problem is concerned with the difference between observed areal units of water depth or amount of irrigated water and areal units of land suitability employed in each case. It may be unreasonable to treat these two factors in the analysis of variance for two variable case. The error sum square (or noize) in this analysis is considerable.

4. Discussion of the results of multiple regression analysis

A simple correlation coefficient matrix was calculated. Those coefficients were proved to be generally very low, except for those combinations having a high correlation as a matter of course. Each factor could safely be considered as independent.

Coefficients for the regression equation with three independent variable were determined on the assumption that transplanted rice yield is explained by the sum of linear effect of the following three factors; a) efficiency of irrigation as an index of the state of consolidation of the water distribution system, b) depth of water as an index of water supply stability, and c) land suitability as an index of soil and topographical environment. Coefficients were determined with significant t-value for each as shown in Table 4. The simple correlation coefficient between each factor and yield was extremely low; the partial correlation coefficient was also very low, although not insignificant. The multiple correlation coefficient was 0.61 (or 0.56 when adjusted for degrees of freedom), the coefficient of determination consequently being 0.37 (or 0.31 when thus adjusted). This means that the regression equation thus determined can only explain approximately one third of the yield differential, the other two thirds to be explained by other factors, such as rice variety, rate of fertilizer application, standard of general

Table 4 Multiple regression analysis

Factor	Coefficient	Standard error	t-value	Correlation coefficient partial	simple
Efficiency of irrigation	0.873	0.433	2.0*	0.33	0.32
Water depth in the field at the heading stage	−2.491	0.924	−2.7*	−0.42	−0.35
Land suitability I+IV	512.1	39.5	13.0**	0.91	0.34
Land suitability II+III	454.9	38.4	11.8*	0.90	−0.34

$R=0.607$, $R^2=0.368$　　DW=0.76

$r=0.559$, $r^2=0.313$ (adjusted for degrees of freedom)　Sample size=38

farming techniques, quality and quantity of farm labor invested, and errors involved in the measurement and transformation of environmental unit factors. One cannot distinguish these latter factors by this kind of statistical analysis.

When surplus or deficit irrigated water, or total water supply were put in the place of efficiency of irrigation in the equation, the t-value of each coefficient was significant, although the coefficient of determination in these cases did not improve. They were 0.30 and 0.27 (adjusted for degrees of freedom) respectively. But when too many factors appear in the regression equation, the coefficient of determination did not exceed 0.31. At the same time, the t-value of each coefficient became insignificant.

5. General discussion

Water regimes and soil conditions (preferably expressed as land conditions) were the main subject of study in this paper's attempt to determine the effect of natural environmental factors on rice yield. The most pronounced factors that appeared were as follows ; a) efficiency of irrigation and surplus or deficit of irrigated water can be taken as indexes to indicate the state of consolidation of a water distribution system ; b) average depth of water in field at the heading stage is a key factor ; and c) land suitability is the most appropriate index of both soil and topographic environment. These three factors proved to explain about one third of the yield differential of both transplanted and broadcast rice. The author feels that this is not a bad value for the total effect of natural environmental conditions on yield, although there is, of course, some latitude for other interpretations.

As for water environment, results of analysis indicate that yield is higher under shallow water conditions with a depth less than ca. 15 cm and under comparatively smaller amounts of irrigated water. Perhaps stated correctly, when we consider that high yield level can be expected a) under stable conditions of water supply where a crop can be grown in shallow water for a comparatively longer period and b) where there are good systems of water distribution so that smaller amounts of water can be distributed evenly to the rice fields. For example, a yield of 500 kg/rai for transplanted rice was attained in an area where efficiency of irrigation exceeds 70 % ; this left less than 300 mm of irrigation surplus. The same holds true also for broadcast rice.

As for land suitability, a yield differential of 50-60 kg/rai appeared between I+IV and II+III land suitability areas.

Statistical analysis can only describe comparatively superficial phenomena; deeper interpretation must be gained by using additional methods. Study of the physical cause and effect of environmental factors on yield level awaits new methods of analysis and innovative experimental studies.

Acknowledgements

The author owes thanks to many persons. Mr. Charin Atthayodhin, Mr. Paituun Palayasuut and Mr. Chuchawal Sawatdirurk, all of the Royal Irrigation Department of Thailand, offered much kind assistance to the author that helped enable him carry out his field observation tours and collect various kinds of field level data. Without the assistance given by the officers of each project office and field office of the Royal Irrigation Department, this study could not have been carried out. Thanks are also due to Dr. K. Kyuma, Mr. H. Fukui, and Mr. H. Tsujii for their valuable discussion in the course of analyzing data. The author is also indebted to Mr. Y. Sakai for his advice on computer techniques and to Mrs. K. Iwanaga for her assistance in arranging and computing the data.

Appendix 1 The criteria for land and soil classification

	Soil classification									
	00	01	02	03	04	05	06	07	08	09
Great soil group	I				III		II	III		IV
Parent material + Land form		I	II	III	IV	V	VI	VII	(VIII)	IX
Land form	I		IV	III	IV	III	II	V		VI

Note: Soil Classification
00: Alluvial soil (Marine alluvium)
01: Alluvial soil (Brakish alluvium)
02: Alluvial soil (Recent river levee alluvium)
03: Alluvial soil (Recent river basin alluvium)
04: Low humic gley soil (Semi-recent river levee alluvium)
05: Low humic gley soil (Semi-recent river basin or terrace alluvium)
06: Grumsol (Semi-recent alluvium-montmorillonite clay)
07: Low humic gley soil (Low terrace sediments)
08: Colluvium
09: Alluvial or slope complexes

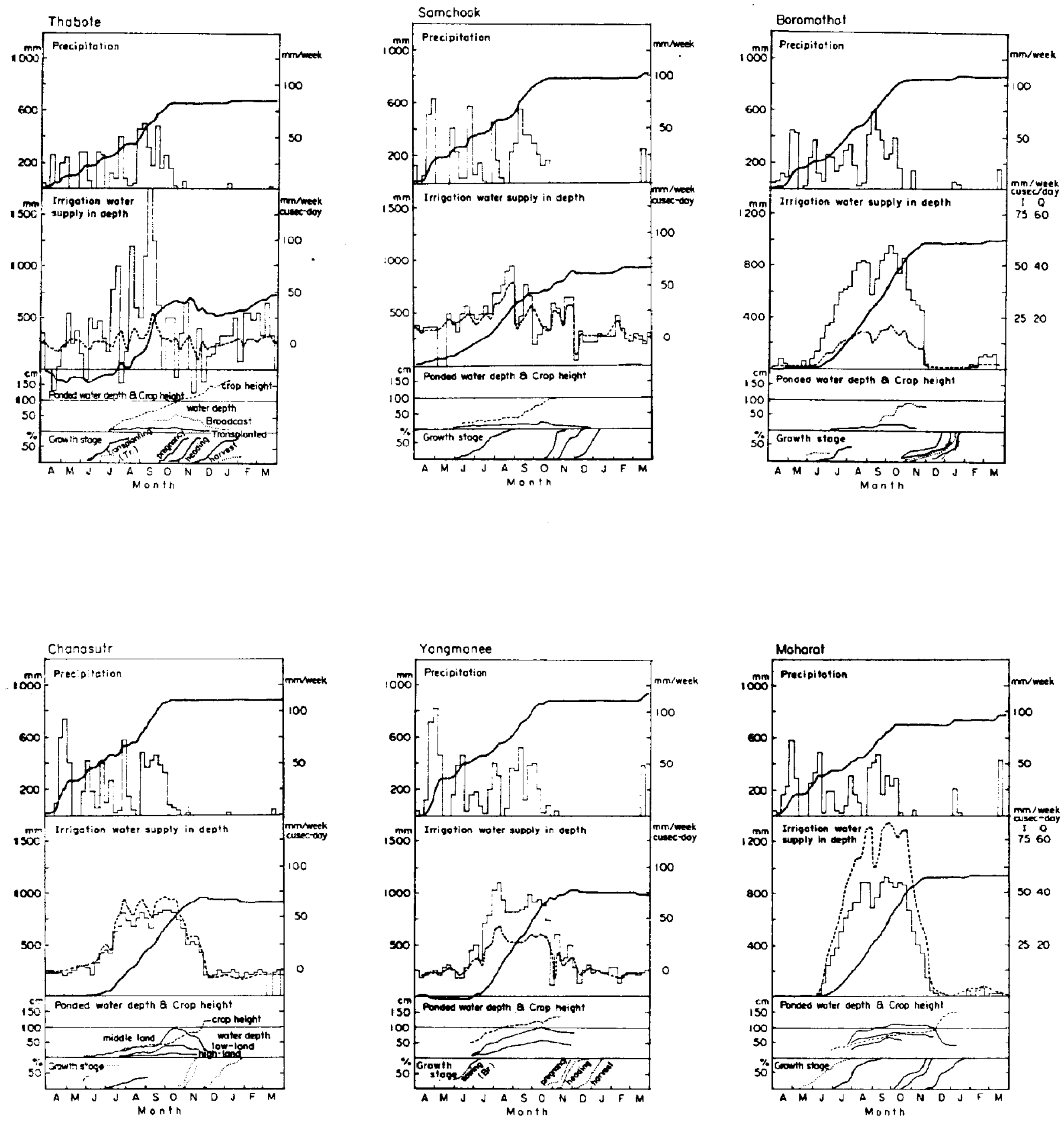
Land suitability for irrigated rice

Class I includes soil series of Banglen, Chainat, Ratburi, Chumsaeng, Phimai, Phimai-light textured phase, Krok Phra, Manorom, Manorom-light textured phase, Saraburi, Saraburi-high phase, Nakhon Pathom, Nakhon Pathom-red mottled phase, Nakhon Pathom-dryland phase, Bang Mee, Chongkae, Khoke Krathiam, Khoke Krathiam-light gray phase, and Deum Bang-clyey phase.

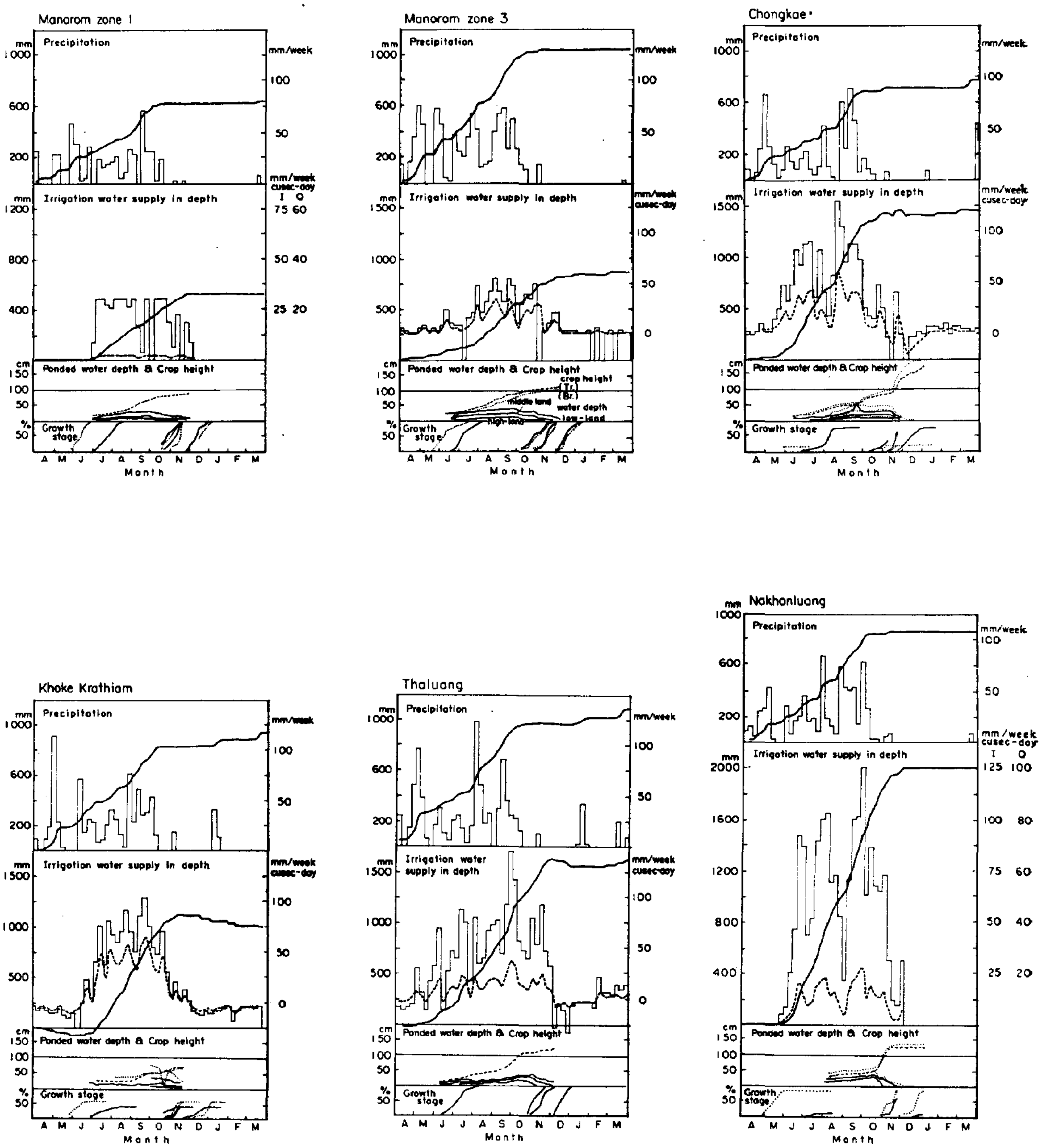
Class II includes soil series of Bangkhen, Ongkarak, Rangsit, Thamuang-clayey phase, Sapphaya, Phimai in Khoke Krathiam project, Phetburi, Pholathep unnamed, Bang Mee in Khoke Krathiam project, Lopburi, Lopburi-lower phase, Khoke Krathiam in Chongkae and Khoke Krathiam project, Deum Bang, and Deum Bang-red mottled phase.

Class III includes soil series of Bangkhen-undulating phase, Thamuang, Phimai in Maharat project, Phimai-undulating phase, Ratburi/Phimai, Saraburi/Phimai, Yang Pong, Kampaeng Saen, Thatako, Don Chedi, Hingkong, Phen, Phon Phi Say, Sattahip, and Thabote unnamed.

Class IV includes Alluvial complexes and Slope complexes.



Appendix 2 Weekly variations of precipitation, irrigation water supply, water depth in the field, crop height, and rice plant growth stages in each Project in 1968 water year (Compiled from the 1968 crop outlook reports of the RID)



Appendix 2 (continued)

Appendix 3 The rearrangement of each factor in each zone, readjusted from data at each sampling plot

(1) Transplanted Rice

NO	TB	Project	YIELD	PER 1	PER 2	HIGH	RAIN	IRRI	WATER	LOSS	EFF	MAX	MEAN	TEMP
1	1	Pholathep 1	0.528	20	12	−1	700	773	1473	354	54	−1	−1	590
2	1	Pholathep 2	0.536	21	13	−1	700	586	1286	118	80	−1	−1	620
3	1	Thabote 1	0.495	24	15	165	490	880	1370	156	82	18	12	700
4	1	Thabote 2	0.541	25	15	160	490	880	1370	156	82	13	10	830
5	1	Thabote 3	0.480	24	14	155	360	880	1240	108	88	16	11	700
6	1	Thabote 4	0.423	25	15	167	360	880	1240	59	93	12	10	830
7	1	Thabote 5	0.531	25	15	150	490	620	1110	−103	117	12	10	765
8	1	Thabote 6	0.539	24	14	157	360	620	980	−152	125	15	11	700
9	1	Samchook 6	0.362	22	14	104	570	760	1330	145	81	16	12	760
10	1	Samchook 7	0.426	26	18	125	610	790	1400	10	99	24	16	760
11	1	Samchook 8	0.462	23	13	116	560	770	1330	197	74	25	16	630
12	1	Samchook 9	0.498	23	14	105	580	790	1370	183	77	22	9	630
13	1	Samchookext 1	0.505	23	14	114	560	880	1440	258	71	24	19	680
14	1	Samchookext 2	0.405	22	12	113	490	870	1360	293	66	23	17	650
15	1	Samchookext 4	0.378	22	12	125	530	880	1410	333	62	22	19	650
16	1	Phophraya 1	0.437	24	16	−1	550	1130	1680	402	64	−1	−1	710
17	1	Phophraya 3	0.468	24	15	−1	550	1130	1680	451	60	−1	−1	710
18	1	Phophraya 4	0.326	−1	−1	−1	550	1180	1730	−1	−1	−1	−1	−1
19	1	Boromathat 1	0.528	24	15	−1	500	790	1290	74	91	20	11	700
20	1	Boromathat 2	0.502	26	20	−1	510	810	1310	−143	118	20	10	760
21	1	Boromathat 3	0.504	26	20	−1	600	910	1510	24	97	20	10	760
22	1	Boromathat 4	0.434	26	20	−1	590	930	1520	36	96	20	10	760
23	1	Chanasutr 1	0.623	23	13	138	480	910	1380	277	70	38	26	643
24	1	Chanasutr 2	0.535	21	11	138	480	910	1380	375	59	38	30	590
25	1	Chanasutr 3	0.494	20	11	138	470	910	1370	367	60	38	28	590
26	1	Chanasutr 4	0.468	22	13	135	470	910	1370	269	70	38	30	640
27	1	Chanasutr 5	0.461	20	11	134	480	880	1360	345	61	43	28	590
28	1	Chanasutr 6	0.514	21	12	90	500	910	1400	341	63	38	27	590
29	1	Chanasutr 7	0.476	24	15	90	600	880	1490	239	73	38	28	700
30	1	Yangmanee 1	0.542	22	13	105	430	990	1430	319	68	48	44	650
31	1	Yangmanee 2	0.443	19	11	100	560	890	1450	415	53	41	31	560
32	1	Yangmanee 3	0.472	21	11	110	430	980	1410	407	58	40	32	620

Appendix 3 (continued)

33	1	Yangmanee 4	0.439	21	11	135	430	980	1410	407	58	55	50	620
34	1	Yangmanee 5	0.475	25	15	90	630	990	1620	371	62	40	35	740
35	1	Yangmanee 6	0.458	24	14	100	460	1040	1500	343	67	30	25	710
36	1	Yangmanee 7	0.446	23	13	115	430	940	1370	269	71	50	43	680
37	1	Maharat 1	0.458	22	14	135	605	906	1510	318	65	26	19	650
38	1	Maharat 2	0.477	22	13	129	500	930	1430	312	66	32	23	640
39	1	Maharat 3	0.579	21	13	120	370	890	1250	174	80	30	30	610
40	1	Maharat 4	0.534	20	12	150	390	910	1300	258	72	70	70	590
41	1	Manorom 1	0.594	20	13	102	400	530	910	−163	131	18	7	590
42	1	Manorom 2	0.608	23	14	99	610	760	1370	175	77	22	7	650
43	1	Manorom 3	0.522	24	16	108	690	760	1450	137	82	26	10	710
44	1	Chongkae 1	0.652	20	13	90	620	1260	1880	732	42	17	9	590
45	1	Chongkae 2	0.540	19	11	88	440	1210	1650	645	47	16	10	560
46	1	Chongkae 3	0.438	19	12	175	460	1260	1710	661	48	20	18	530
47	1	K. Krathiam 1	0.540	21	12	80	490	1160	1650	583	50	16	9	620
48	1	K. Krathiam 2	0.481	21	12	80	490	1160	1650	583	50	18	8	620
49	1	K. Krathiam 3	0.540	23	14	73	490	1160	1650	485	58	20	8	680
50	1	Roengrang 1	0.540	22	12	126	520	−1	−1	−1	−1	15	5	650
51	1	Roengrang 2	0.571	25	18	130	520	−1	−1	−1	−1	20	5	737
52	1	Roengrang 3	0.760	−1	−1	140	−1	−1	−1	−1	−1	50	−1	−1
53	1	Roengrang 5	0.399	21	11	136	490	−1	−1	−1	−1	25	7	620
54	1	Roengrang 6	0.421	22	14	140	490	−1	−1	−1	−1	21	6	650
55	1	Roengrang 7	0.436	24	13	135	490	−1	−1	−1	−1	14	5	710
56	1	Roengrang 8	0.433	21	11	113	490	−1	−1	−1	−1	14	4	620
57	1	Roengrang 9	0.400	21	12	136	490	−1	−1	−1	−1	30	10	620
58	1	Roengrang 11	0.424	22	11	149	570	−1	−1	−1	−1	38	10	650
59	1	Thaluang 2	0.494	21	15	120	590	1460	2050	811	44	18	7	630
60	1	Thaluang 4	0.501	21	13	124	620	1475	2090	947	36	20	6	570
61	1	Thaluang 5	0.645	23	15	130	620	661	1280	35	95	27	13	690
62	1	Thaluang 6	0.470	23	14	122	620	661	1280	84	87	18	14	690
63	1	N. Luang 1	0.538	19	10	90	500	3730	4220	3259	13	14	4	570
64	1	N. Luang 2	0.469	20	11	114	560	4230	4790	3755	11	22	10	630
65	1	N. Luang 3	0.390	23	18	125	600	4230	4830	3442	19	30	12	690
66	1	N. Luang 4	0.423	20	10	90	500	3730	4220	3259	13	30	12	−1

Appendix 3 (continued)

(2) Broadcast Rice

NO	TB	Project		YIELD	PER 1	PER 2	HIGH	RAIN	IRRI	WATER	LOSS	EFF	MAX	MEAN	TEMP
1	0	Thabote	5	0.463	31	23	162	530	620	1160	−202	133	85	57	870
2	0	Samchookext	4	0.542	33	23	136	650	880	1530	147	83	63	15	890
3	0	Phophraya	4	0.320	31	17	−1	620	1180	1800	711	40	−1	−1	910
4	0	Phophraya	5	0.396	31	22	−1	650	1190	1850	505	58	−1	−1	910
5	0	Boromathat	3	0.487	34	28	−1	680	930	1577	−18	102	90	80	990
6	0	Boromathat	2	0.517	34	29	−1	610	810	1420	−238	129	90	80	990
7	0	Chanasutr	2	0.311	31	21	138	580	940	1520	250	73	90	79	880
8	0	Chanasutr	4	0.373	30	21	135	620	940	1560	280	70	98	78	760
9	0	Chanasutr	5	0.422	31	22	134	730	940	1670	315	66	100	82	910
10	0	Chanasutr	6	0.419	29	20	195	730	920	1650	390	58	100	80	820
11	0	Chanasutr	7	0.428	30	21	195	850	920	1770	433	53	100	83	880
12	0	Chanasutr	1	0.490	31	22	138	640	920	1560	228	75	95	72	910
13	0	Yangmanee	3	0.353	28	19	150	670	1030	1690	503	51	70	60	830
14	0	Yangmanee	4	0.313	29	19	170	610	1030	1640	458	56	100	85	830
15	0	Phakhai	1-5	0.483	32	24	−1	720	−1	−1	−1	−1	75	69	950
16	0	Phakhai	6	0.613	34	25	−1	510	−1	−1	−1	−1	110	96	1010
17	0	Maharat	1	0.486	29	21	136	750	930	1680	368	60	60	43	850
18	0	Maharat	2	0.489	29	20	132	560	930	1490	273	71	63	48	850
19	0	Maharat	3	0.382	30	21	140	540	930	1470	210	77	70	60	850
20	0	Maharat	4	0.397	26	18	190	540	930	1470	353	62	110	105	770
21	0	Maharat	5	0.418	26	17	175	800	930	1730	596	36	123	90	760
22	0	Maharat	6	0.439	27	21	145	800	930	1730	405	56	80	65	790
23	0	Maharat	7	0.277	30	22	165	710	930	1630	290	69	90	70	880
24	0	Manorom	1	0.437	27	19	98	530	530	1060	−102	119	32	16	790
25	0	Manorom	2	0.529	26	18	97	720	530	1250	88	83	33	17	770
26	0	Manorom	3	0.395	28	20	117	820	790	1610	328	59	40	21	850
27	0	Chongkae	2	0.308	30	22	170	630	1370	2010	670	51	36	25	890
28	0	Chongkae	1	0.479	32	24	100	760	1380	2140	682	51	30	17	940
29	0	Chongkae	3	0.367	29	23	195	630	1380	1935	632	54	50	42	860

Appendix 3 (continued)

30	0	K. Krathiam 1	0.406	29	19	98	590	1110	1690	523	53	90	50	850
31	0	K. Krathiam 2	0.335	30	21	105	620	1110	1730	450	59	85	45	880
32	0	K. Krathiam 3	0.213	30	20	93	580	1110	1690	468	58	78	35	880
33	0	K. Krathiam 4	0.507	33	23	109	620	1100	1720	345	69	100	52	950
34	0	Roengrang 14	0.372	32	23	−1	710	−1	−1	−1	−1	50	38	940
35	0	Roengrang 12	0.544	32	23	146	710	−1	−1	−1	−1	48	28	940
36	0	Roengrang 13	0.462	32	23	156	710	−1	−1	−1	−1	76	28	940
37	0	N. Luang 2	0.436	30	20	124	690	4710	5410	4150	12	34	18	890
38	0	N. Luang 3	0.423	32	21	132	790	4710	5510	4178	11	32	12	950
39	0	N. Luang 4	0.421	33	22	138	710	4710	5420	4070	14	42	35	980

Note:

TB: TB 1 denotes transplanted rice, while TB 0 does broadcast rice
YIELD: Unhusked rice yield in ton per rai
PER 1: Whole rice growing period
PER 2: Vegetative growing period
HIGH: Crop height (cm)
RAIN: Precipitation (mm)
IRRI: Irrigation water supply (mm)
WATER: Total water supply (mm)
LOSS: Surplus or deficit irrigated water (mm)
EFF: Efficiency of irrigation (%)
MAX: Maximum ponded water depth in the field (cm)
MEAN: Ponded water depth at the heading stage (cm)
TEMP: Cumulative temperature during entire growing period (week-degrees)

Figures of −1 denote data not available